Durability theory

Claisse, P.A.

2.9 DURABILITY THEORY

- 2.9.1 Introduction
- 2.9.2 Types of failure
- 2.9.3 Transport processes in concrete
- 2.9.4 Corrosion of reinforcement
- 2.9.5 Sulphate attack
- 2.9.6 Alkali-silica reaction
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- 2.9.8 Salt crystallisation
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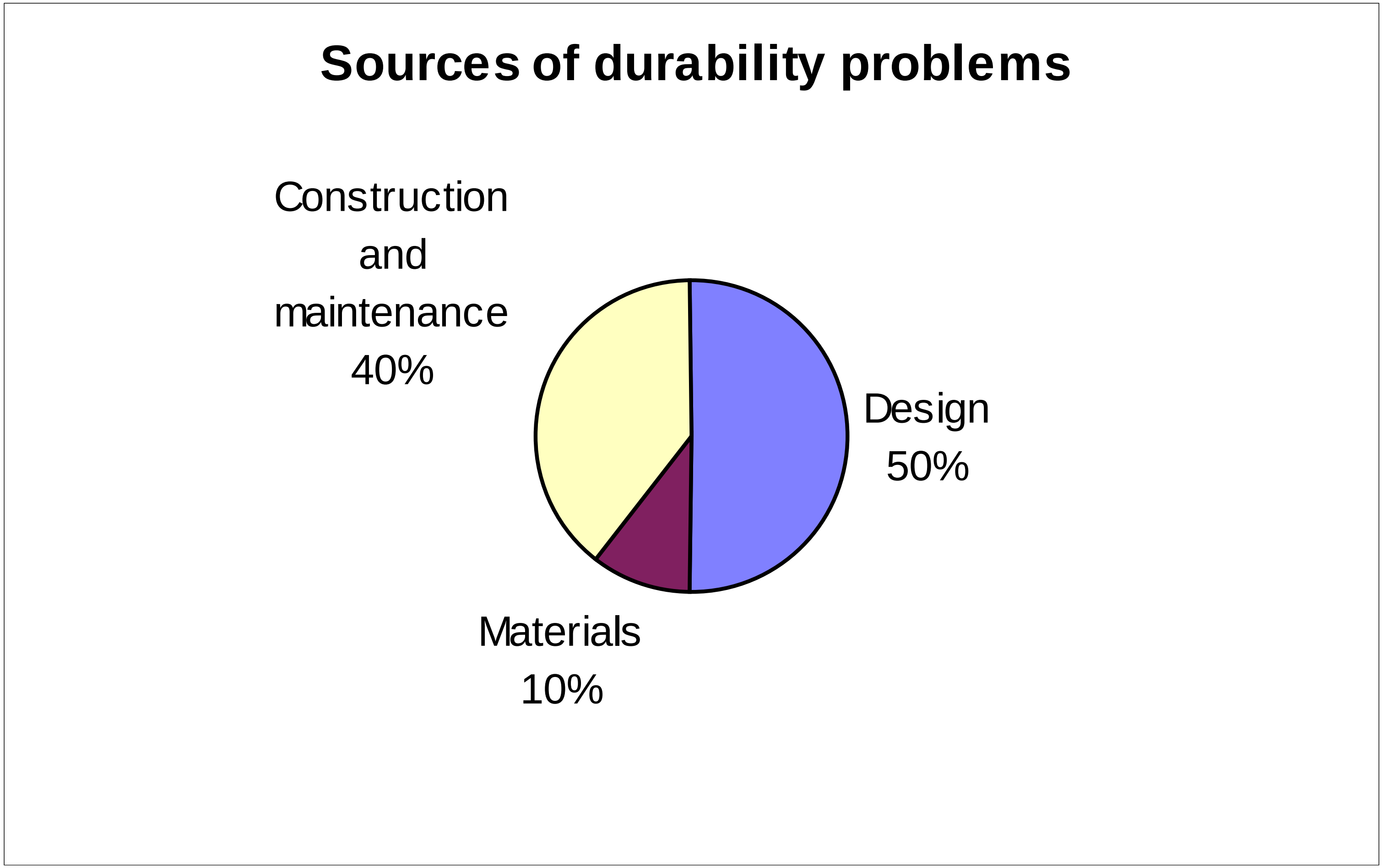
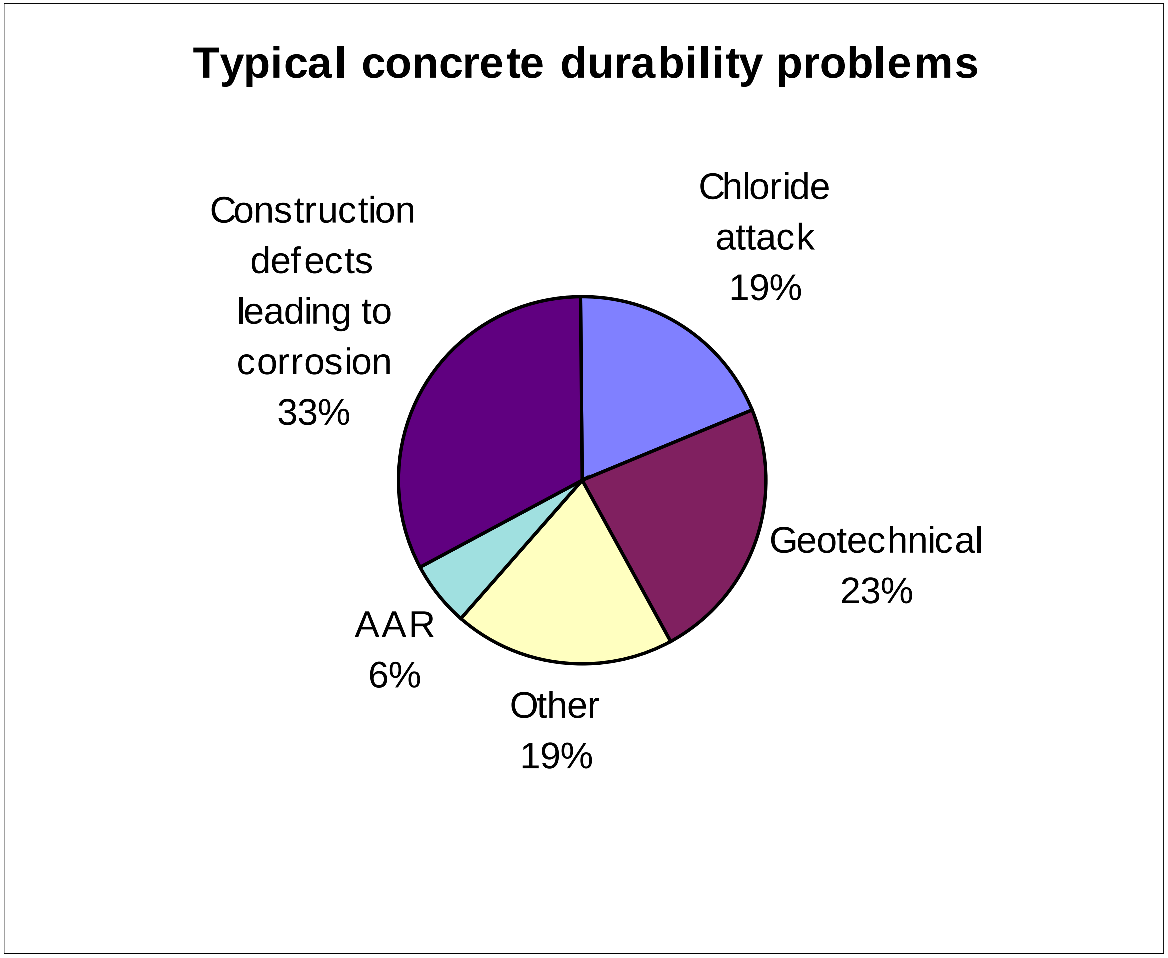
- *Why Reinforced Concrete Structures Don’t Fall Down*

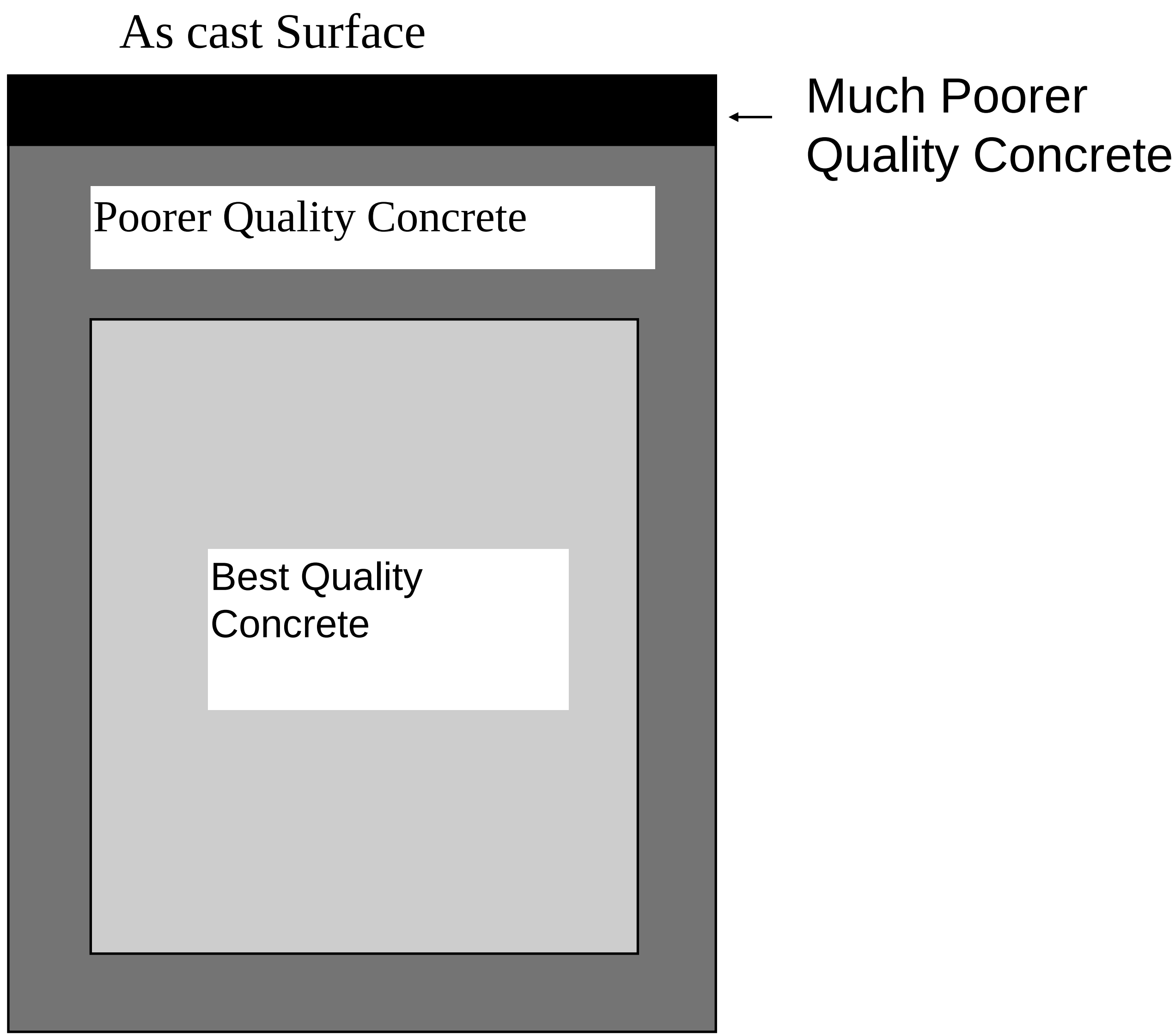
Sources of Durability Problems



Types of Durability Problems



Concrete in a Structure



2.9 DURABILITY THEORY

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Factors Affecting Durability

<table>
<tr><th colspan="11">.Factors Adversely Affecting Durability</th></tr>
<tr><td colspan="6">External factors</td><td colspan="3">Internal causes</td><td colspan="2">Structural Causes</td></tr>
<tr><td colspan="2">Weathering</td><td colspan="3">Chemical Action</td><td>Mechanical action</td><td>Salts</td><td>Volume Changes</td><td>Alkali Aggregate Reaction</td><td>Joint Provision</td><td>Over-load</td></tr>
<tr><td>Freeze Thaw</td><td>Temperature and moisture variations</td><td>Inorganic Salts</td><td>Carbonation</td><td>Acids</td><td>Water Wind Traffic</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Spalling and loss of strength</td><td>Cracking leading to loss of durability</td><td colspan="2">May cause rebar corrosion</td><td colspan="2">Surface erosion</td><td>Chlorides may cause rebar corrosion</td><td>Cracking leading to loss of durability</td><td>May cause loss of strength and durability</td><td colspan="2">Cracking leading to loss of durability</td></tr>
</table>

Fig 2.9.4

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What is being transported ?

- Ions (e.g. Na^+ and Cl^-) may move through the water

OR

- Water itself may move with the ions in it

The Transport Processes

- Pressure driven flow
- Diffusion,
- Electromigration
- Thermal migration

Processes which Promote or Inhibit Transport

- Adsorption (inhibits)
- Capillary suction (promotes)
- Osmosis (promotes)

Electromigration - Where Does the Voltage Come from?

- An external source such as leakage from a direct current power supply
- Electrical potential of pitting corrosion on reinforcing steel.

Factors Affecting Durability

Factors which can be controlled		**Properties of the matrix**		**Transport Processes**		**Deterioration Processes**
		Hydrate Structure		Pressure driven flow		Freeze-Thaw
Water to cement ratio		Pore interconnection (formation factor)		Diffusion		Sulphate Attack
Curing conditions		Porosity (total pore volume)		Electromigration		Alkali-silica reaction
Environmental conditions		Pore fluid content		Thermal Gradient		Reinforcement Corrosion
Degree of compaction		Pore fluid chemistry		Osmosis		Salt Crystallisation
Cement Type		Matrix chemistry		Capillary suction		
				Adsorption		

Reduce the porosity with w/c ratio

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PFA will reduce Electromigration

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Using SRPC will reduce Adsorption

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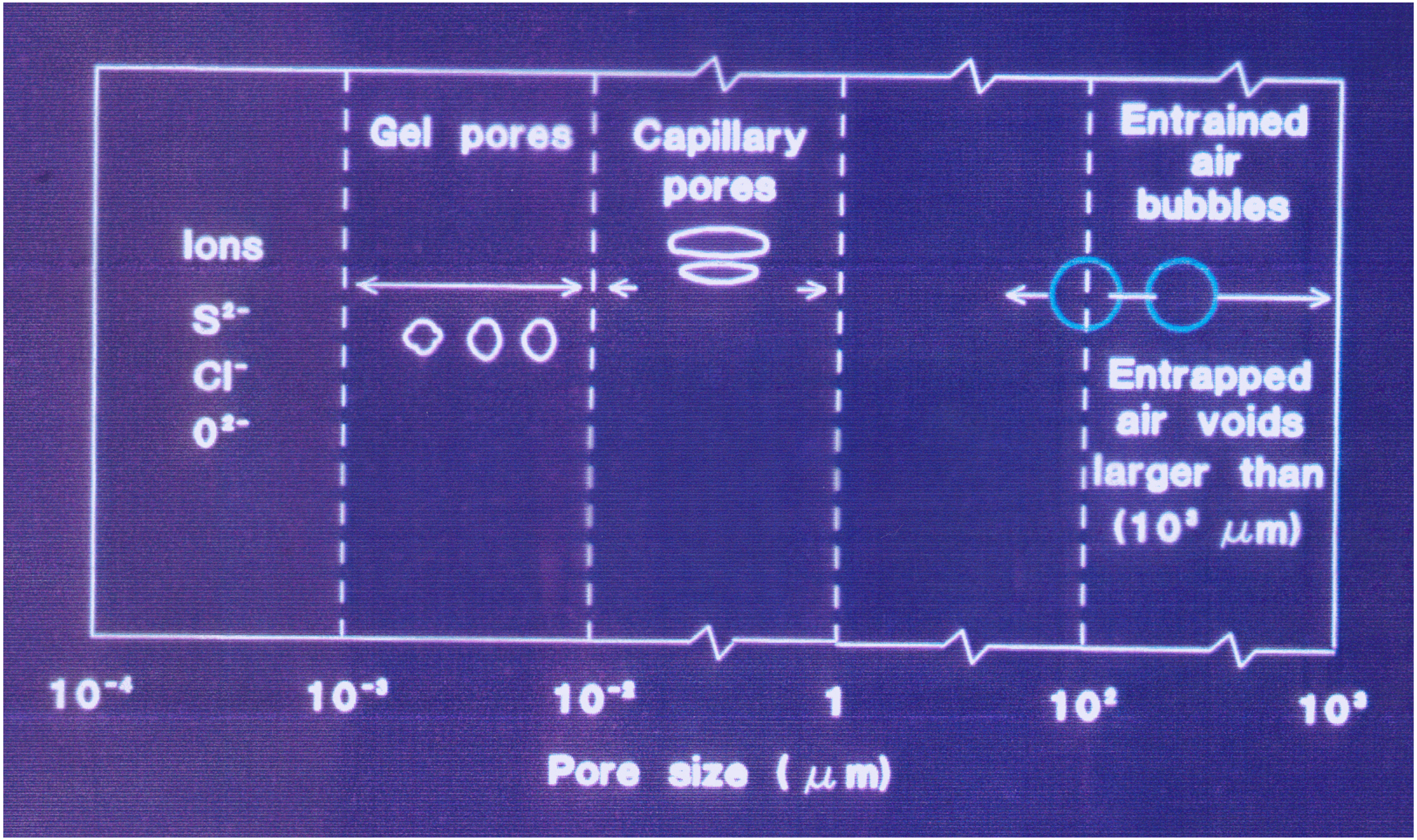
Curing has two distinct functions

1 To stop the concrete from drying out during hydration. If this occurs a significant loss of durability will occur.

2. To retain heat at the surface. This may be done for the following reasons

- i To prevent frost damage (below 5^{o}C)
- ii To increase early strength
- iii To reduce temperature gradients

Types of Pores



Pore Sizes

Size range m	
10^{-10} - 10^{-9}	Ions, S^{2-}, Cl^{-}, O^{2-}
10^{-9} - 10^{-8}	Gel pores: These are part of the hydrated cement structure, they are not interconnected and do not affect durability
10^{-8} - 10^{-6}	Capillary pores: These are connected and considerably affect durability. Their volume may be calculated (see section 2.4). They are formed by excess water which does not react with the cement, either due to a high w/c ratio or insufficient hydration due to poor curing.
10^{-4} - 10^{-3}	Entrained air bubbles: Not interconnected.

2.9 DURABILITY THEORY

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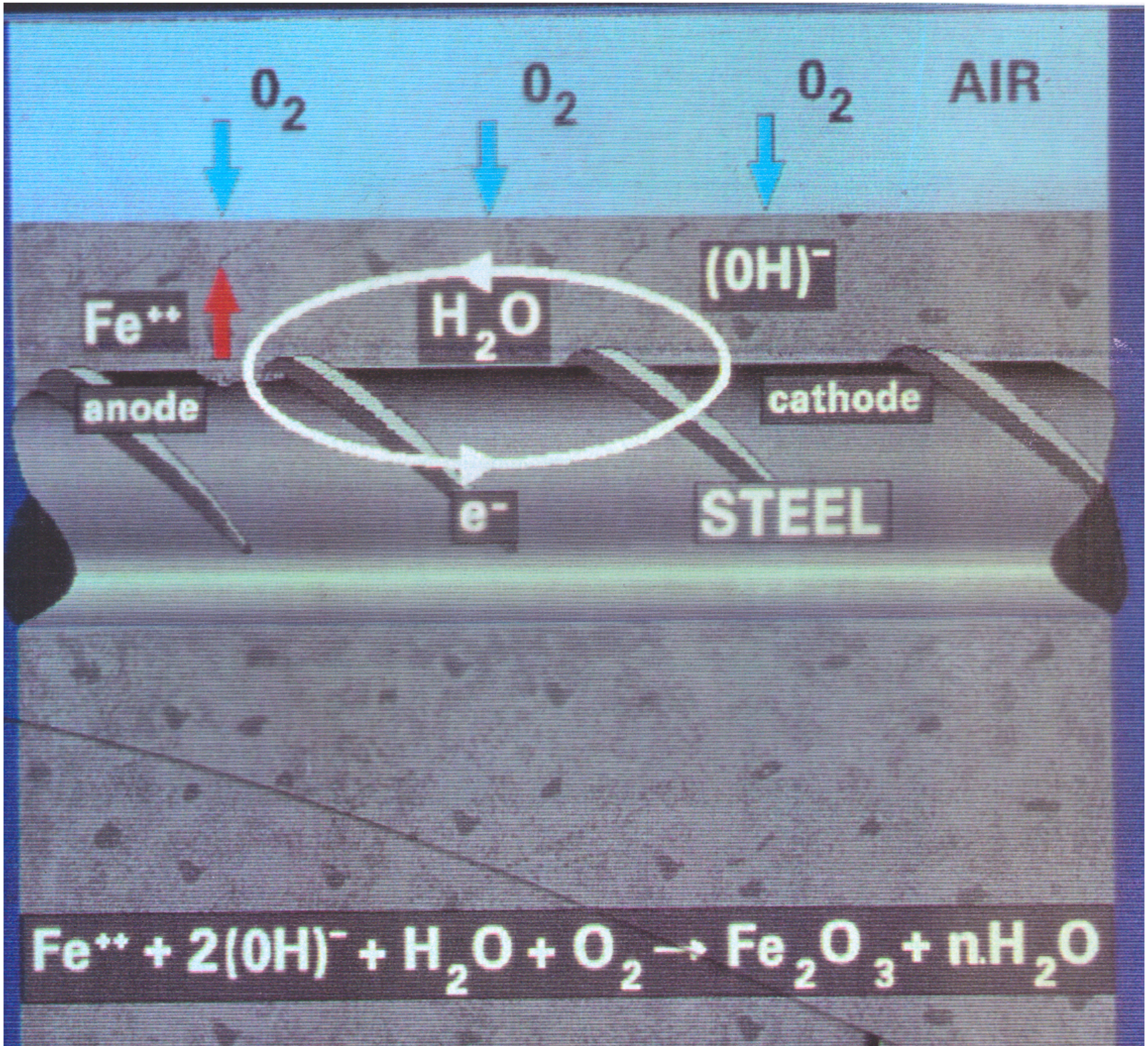
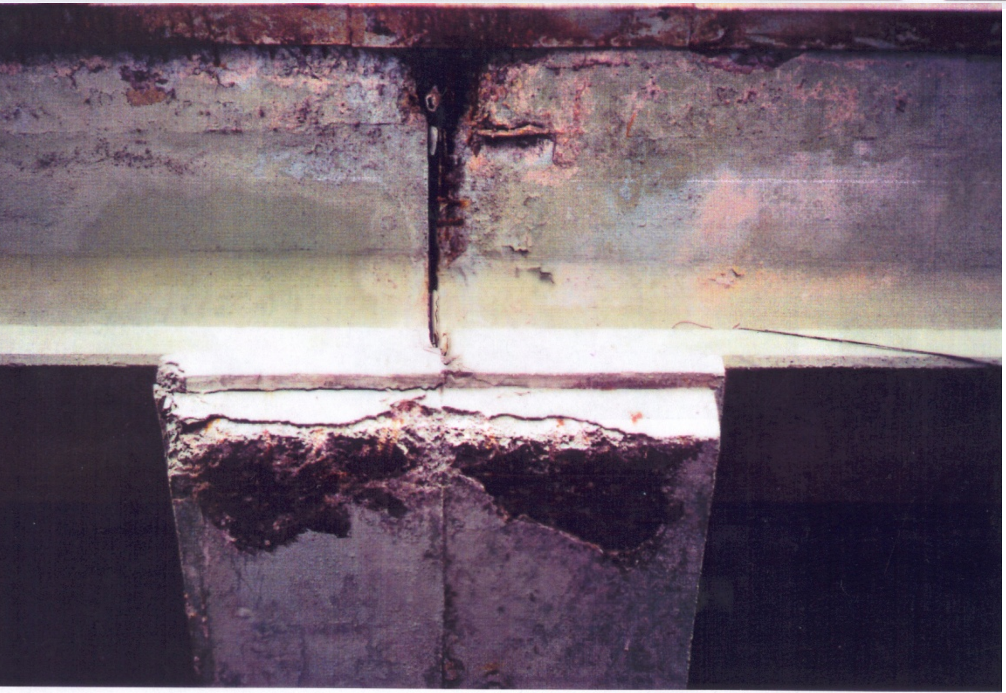
The Corrosion Process



Moscow



Corrosion

Electrochemical reactions producing rust

$Fe \rightarrow 2e^- + Fe^{++}$ Anode

$Fe(OH)_2$

$1/2\ O_2 + H_2O + 2e^- \leftrightarrow 2(OH^-)$ Cathode

$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3$

(red rust - carbonation)

$3Fe + 8OH^- \rightarrow Fe_3O_4 + 8e^- + 4H_2O$

(black rust - chlorides)

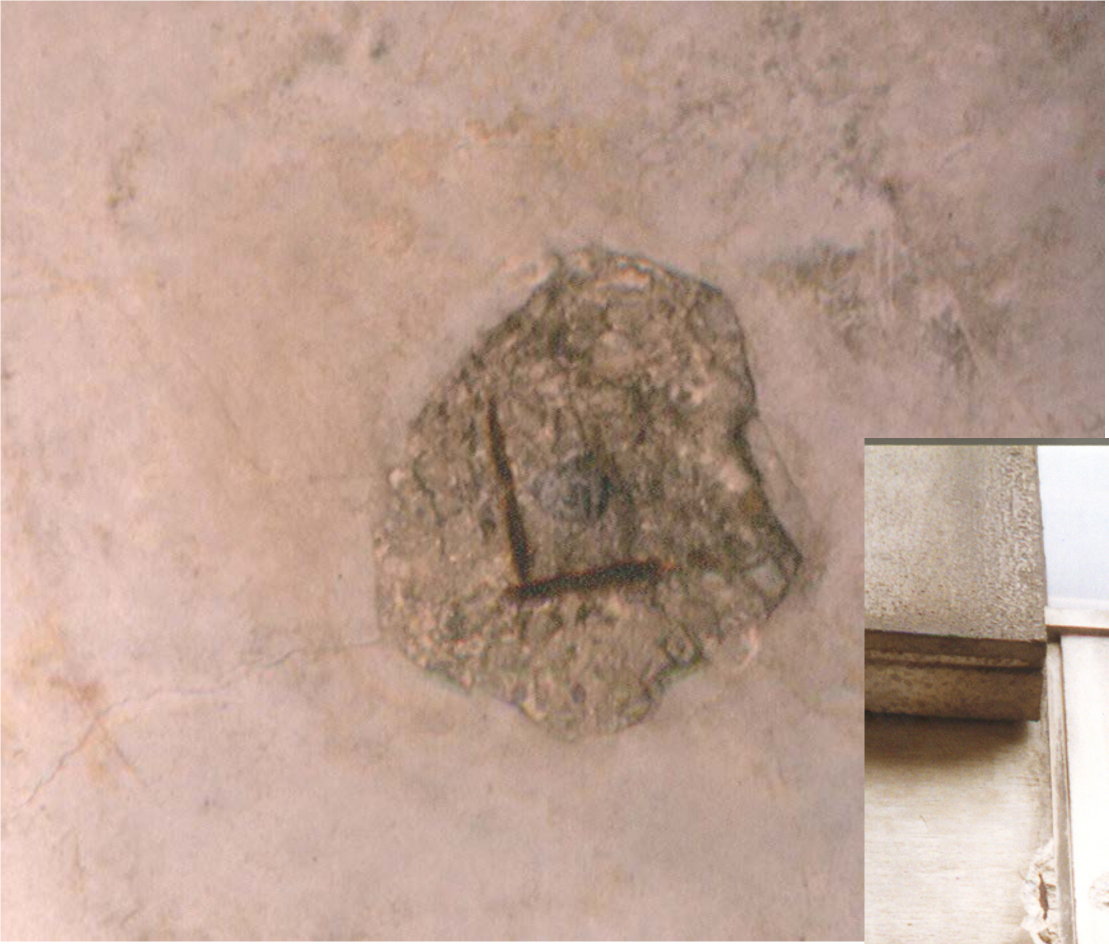
The most significant deleterious agencies affecting passivity and thereby protection to reinforcement are:

- Carbonation (neutralisation of the alkaline pore fluid)
- Chloride ions

Carbonation depths

	Age Years	
Carbonation depth mm	20 MPa concrete	40 MPa concrete
5	0.5	4
10	2	16
15	4	36
20	7	64

Table 2.9.1 Age of concrete for different depths of carbonation



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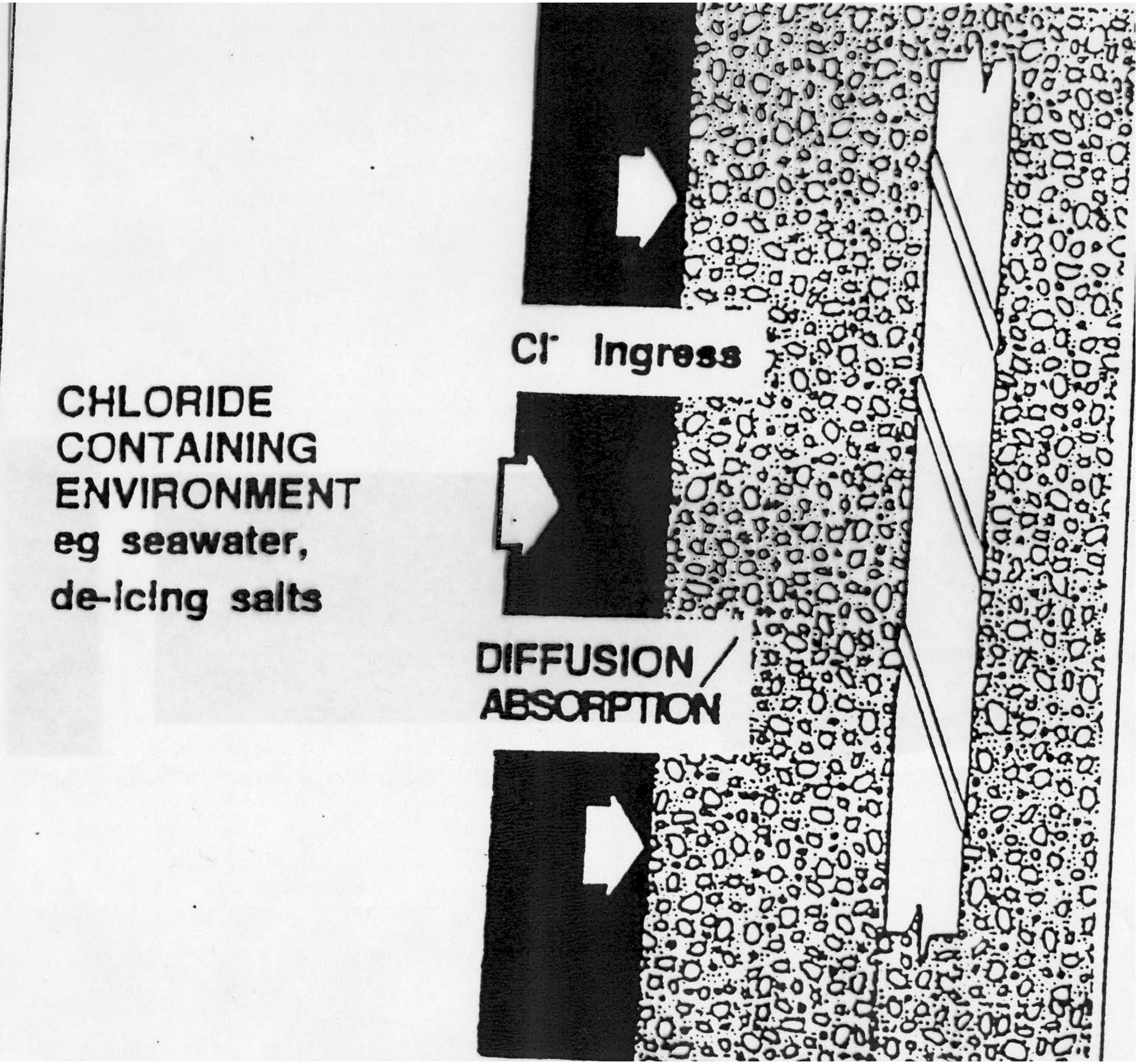
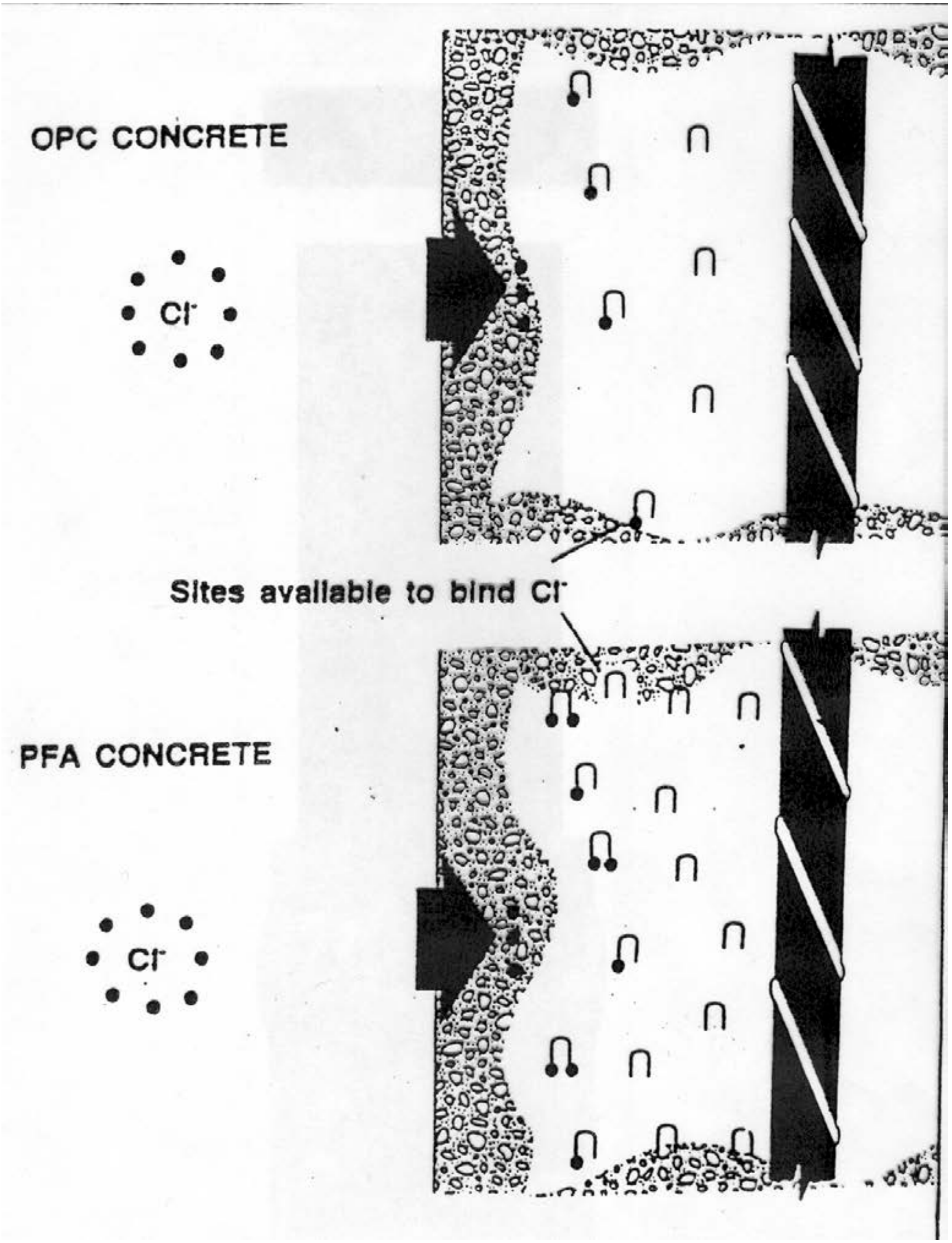


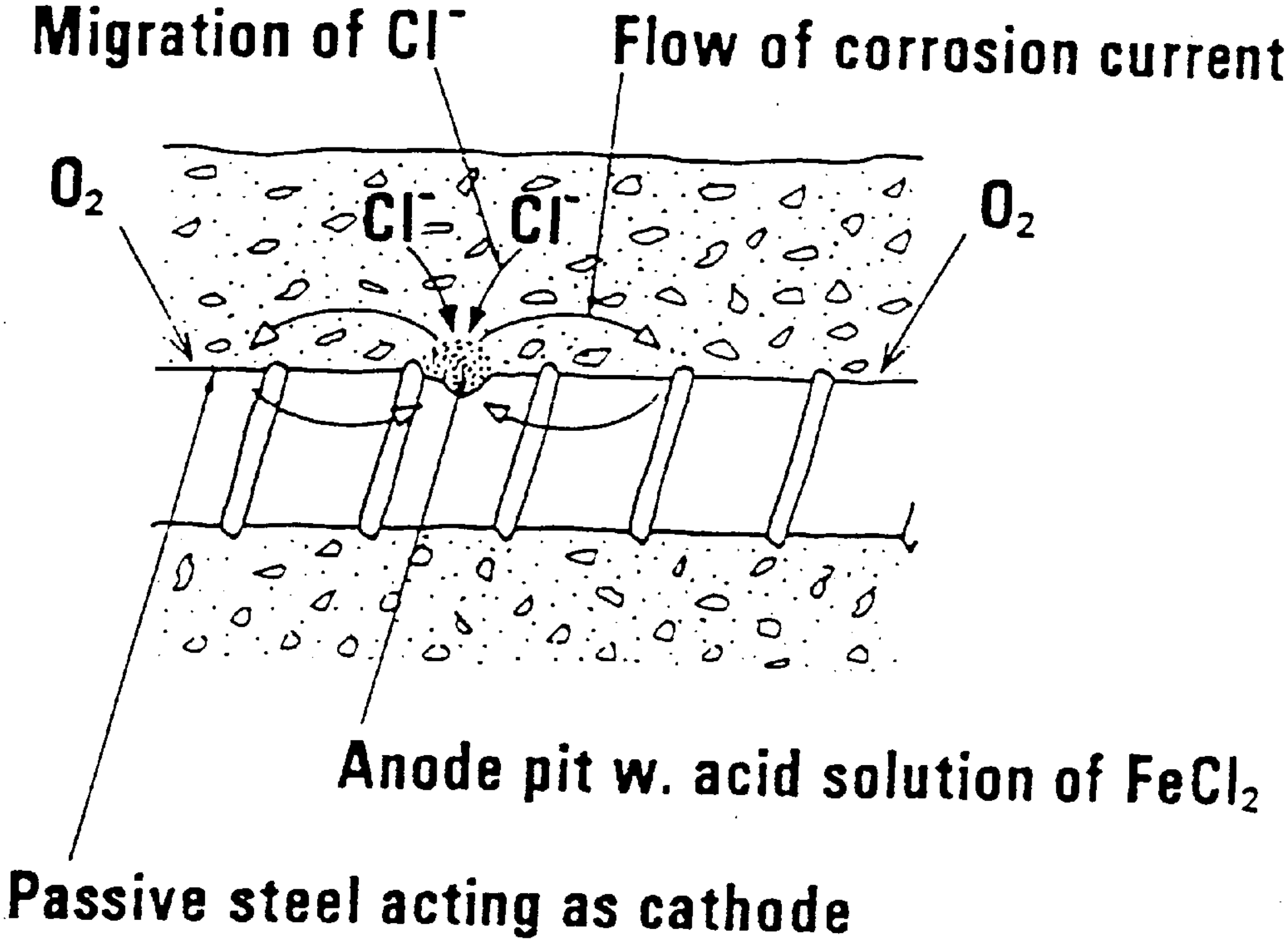
Schematic of chloride ingress



Schematic of binding with PFA

Cracks from Corrosion

Pitting



Migration of Cl⁻
Flow of corrosion current
O₂
Cl⁻
Cl⁻
O₂
Anode pit w. acid solution of FeCl₂
Passive steel acting as cathode

The consequences of the electrical nature of corrosion:

- Reducing the area of the anode (eg by coating part of the corroding steel) may increase corrosion elsewhere.
- Corroding areas may be located by measuring an increased anodic potential.
- Application of a positive potential to the surface of the concrete will stop the corrosion process (cathodic protection).
- Stray currents from welding, conductor rails, contact between different metals etc may produce rapid corrosion by creating an anodic region.
- Using a cementitious material with a high resistivity, such as a pozzolanic mix, will decrease corrosion.

Anode and Cathode on Structure

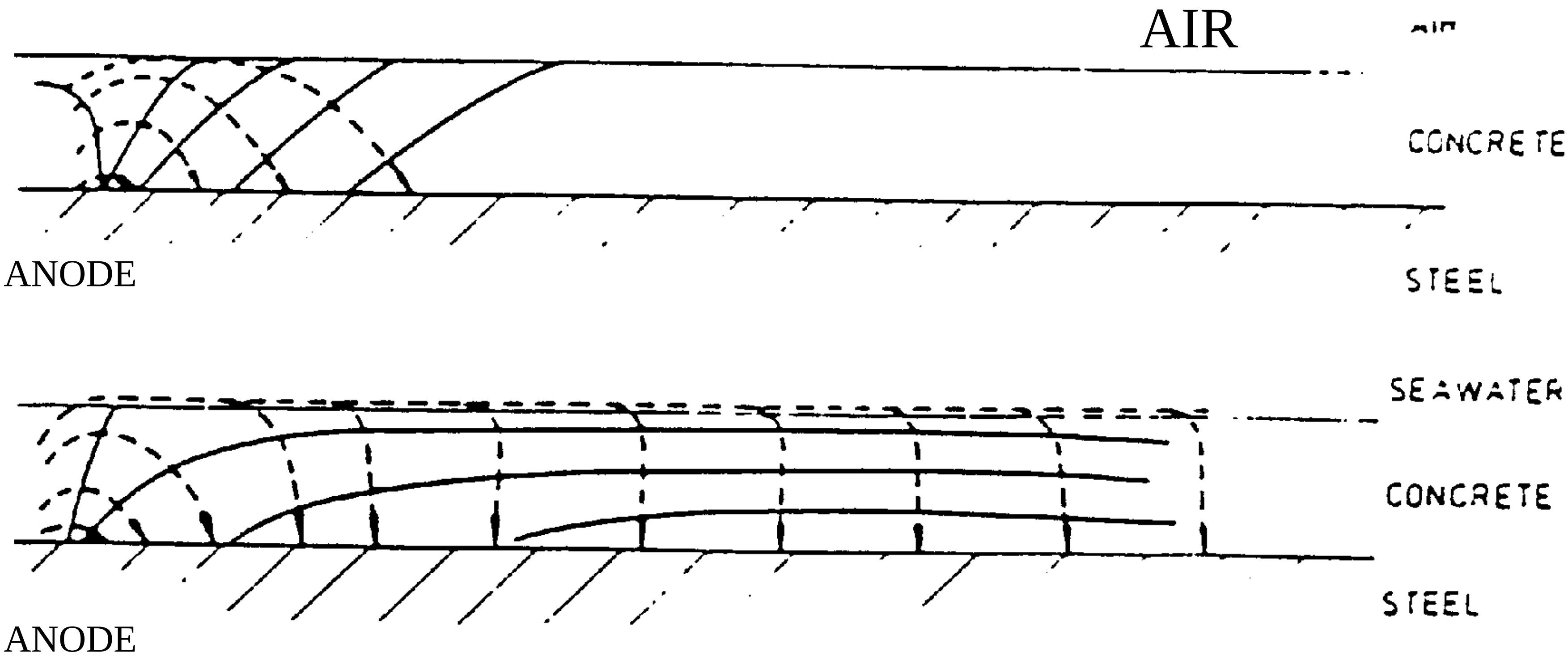


Fig. 8 – Current flow and potential distribution, (a) concrete in air, (b) concrete in sea water. Solid line, equipotential lines; dashed line, current flow.

Egypt

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Sulphate Attack

Common sources of sulphate

- Groundwater
- Sulphate rich soils
- Sea water
- Demolition hardcore

2.9 DURABILITY THEORY

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Frost Attack on Kerb

2.9 DURABILITY THEORY

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Salt Crystallisation

In these two examples there is no damage to the structure (yet)
On the left the water has come from the cooling units above.
On the right it has probably come down the steps from outside.
The source of the salt is not clear. These 2 locations are well away from the car park entrance.

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Why should they fall down?

- The corrosion process is a chemical reaction between oxygen (from the air) and the metal (steel).
- The air and water can move easily through the concrete to the steel.

The main reason why concrete structures don't fall down.

The main products of the reaction between cement and water are:

- Calcium silicate hydrate (CSH gel) - this is the main structural part.
- Lime (calcium hydroxide) – this provides alkalinity that promotes the formation of the passive film that protects the steel.

Chlorides – break down the passive film. Where do they come from?

- External sources: road salt, sea water
- Internal sources: contaminated materials

Transport processes:

- Transport of fluids in solids: permeation (pressure driven flow), capillary suction, thermal gradient, osmosis, and electro-osmosis.
- Transport of ions in fluids: diffusion, electromigration.

How to reduce transport rates in your structures

Increase the depth of cover

or

Reduce the porosity (i.e. the volume of voids) by:

- Reducing the water/cementitious ratio
- Using pulverised fuel ash or Blastfurnace slag (refines the porosity)
- Locally reducing the w/c ratio with controlled permeability formwork
- Good compaction
- Good curing

How to measure the transport properties in your structure:

- Initial surface absorption test,
- Figg gas permeability test,
- Electrical resistivity tests

How the concrete stops the chlorides

- The four cement compounds that make up the CSH gel are:
- Dicalcium silicate, Tricalcium silicate, Tetracalcium alumino-ferrite, Tricalcium aluminate
- The aluminate reacts with chlorides to form immobile chloro-aluminates.

How to protect your structure by promoting the adsorption of chlorides

- Do not: Use sulphate resisting Portland cement – it has a lower aluminate content.
- Do: Use pulverised fuel ash or blastfurnace slag. They have additional adsorption sites.

How the chlorides get moving again…. Carbonation

- The reaction between lime and carbon dioxide to produce carbonates
- Causes corrosion directly by removing alkalinity
- Makes chloro-aluminates unstable

How to reduce carbonation

- Reduce the transport of carbon dioxide by:
- Using a carbonation resisting coating or using concrete with lower transport rates (as for chlorides)

Corrosion is an electrical process; this may affect your structure in the following ways

- Application of a negative potential to the steel will stop corrosion (cathodic protection)
- Application of a positive potential to the steel (e.g. from welding) will cause corrosion.
- Using a concrete with a high electrical resistivity (e.g. with pfa) will reduce corrosion

Thank you

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